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OBSERVATION OF SPECTRUM OF TEV GAMMA RAYS UP TO 60 TEV FROM THE CRAB AT THE LARGE ZENITH ANGLES

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ABSTRACT

The CANGAROO experiment has observed gamma-ray above 7TeV from the Crab pulsar/nebula at large zenith angle in Woomera, South Australia. We report the CANGAROO data taken in 1992, 1993 and 1995, from which it appears that the energy spectrum extends at least up to 50 TeV. The observed integral spectrum is $(8.4 \pm 1.0) \times 10^{-13}(E/7\,\mathrm{TeV})^{-1.53\pm0.15}$ cm^{-2}s^{-1} between 7 TeV and 50 TeV.

In November 1996, the 3.8m mirror was recoated in Australia, and its reflectivity was improved to be about 90% as twice as before. Due to this recoating, the threshold energy of ~ 4 TeV for gamma rays has been attained in the observation of the Crab at large zenith angle. Here we also report the preliminary result taken in 1996.

INTRODUCTION

The Crab pulsar/nebula has been observed by various energy regions. In the energy region from radio to X-ray, it is well understood as synchrotron emission from high energy electrons accelerated up to ∼100 TeV in the nebula. The higher energy component above ∼1 GeV is considered to be produced by the inverce Compton scattering between these very high energy electrons and ambient photons in the nebula.

Previously following energy regions in the range of IC gamma-rays have been observed. The 0.1–10GeV region has been observed by EGRET, and 0.2–10TeV region, by some imaging air Čerenkov telescopes(IACT). In particular, there are only two dataset around 10 TeV: one

is our previous data above 7 TeV with $\sim 4\sigma$ level uncertainly and the other is the data up to 12 TeV reported by the Themistocle group. The observation of gamma-rays above 10 TeV is the key to understand the IC process in the nebula.

OBSERVATION

The observation was made with the 3.8m telescope of the CANGAROO collaboration between Japan and Australia, which is located at Woomera in South Australia (136°47'E and 31°06'S). The high resolution imaging camera, set at the prime focus, consists of small square-shaped photomultiplier tubes of 10mm $\times$ 10mm size (Hamamatsu R2248). The number of photomultipliers was 220 in 1993 and increased to 256 in 1995 with a perfect square alignment, and giving a total field of view of about 3°. The details of the camera and telescope have already been described in Hara et al. (1992). The reflectivity of the mirror has estimated about 45% in 1994. In November 1996, the mirror was recoated in Angro-Australian Observatory, and the reflectivity of the mirror incresed up to about 90%.

The Crab was observed at zenith angles of 53°–56°in 1992, 1993, 1995 and 1996. In order to monitor the cosmic ray background contained in 'ON-source' data, 'OFF-source' runs were also done as described in Tanimori et al. (1994). The total observation times for on- and off-source runs were 3.51×10^5 s and 2.92×10^5 s, respectively.

ANALYSIS AND RESULT

The imaging analysis procedure applied to the data is similar to that described in Tanimori et al. (1994). Basically, we use the same parameters characterizing the elongated shape of the Čerenkov light image as those used by the Whipple group (Weekes et al. 1989): "width","length", "distance", "conc", and the orientation angle α. The resulting event distributions in the combined 1992, 1993 and 1995 observations are plotted in Fig.1a as a function of α, and the preliminary one in two nights observation in 1996 are plotted in Fig.1b. The number of background events in the α peak region ($\alpha \leq 15°$) was estimated from the flat region of α distribution (30°–90°) of the on-source plot. The statistical significance of the peak in Fig.1a achieved is 8σ. Effects by the bright star (ζ Tau, visual magnitude 3.0), which is located at 1.1° from the Crab and within the field of view of the camera, were investigated by the same procedure applied to 1992 observation. We found no effect which would cause false α peaks.

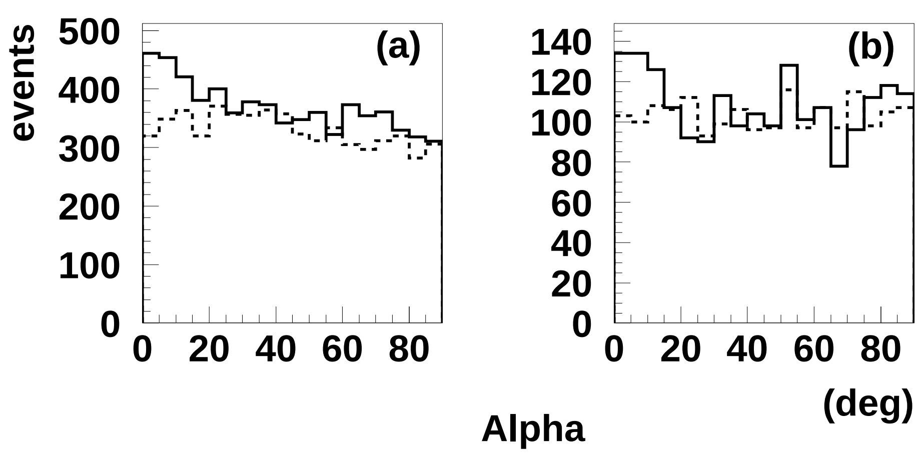

Figure 1: α distribution. (a): until 1995, (b): in 1996.

The collecting area and threshold energy of the telescope for gamma-ray showers have been inferred from a Monte Carlo simulation as described in Tanimori et al. (1994). The integral fluxes of gamma-rays observed are $(8.0 \pm 1.1) \times 10^{-13}$ $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ above $\sim$7 TeV until 1995, and $(2.2 \pm 0.6) \times 10^{-12}$. $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ above $\sim$4 TeV in 1996. The threshold energy is defined as the energy of the maximum differential flux of gamma-ray events expected to be detected by the Monte Carlo simulation.

In order to obtain the integral energy spectrum, α plots were made by varying the minimum number of detected photons, required in the event analysis. The threshold energy corresponding to each α plot was estimated from the simulation.

The resultant integral flux spectrum between 7 TeV and 50 TeV is plotted in Fig.2, and can be written in the form of $(8.4 \pm 1.0) \times 10^{-13} (E/7\,\mathrm{TeV})^{-1.53 \pm 0.15}$ $\mathrm{cm}^{-2}\mathrm{s}^{-1}$. The absolute flux above a few TeV matches well both of the results recently revised by the Themistocle Group (Djannati-Atai et al. 1995) and the Whipple Group (Weekes et al. 1996). The integral index of -1.55 is also consistent with that of the Themistocle group of -1.4 obtained between 2 TeV and 12 TeV and that of the Whipple group of ~ -1.5 from 500 GeV and up to $\sim$10 TeV within 1 σ error. The uncertainties of the energy of the gamma-ray is about 25%, which is due to mainly the errors of the estimations of the number of detected photo-electrons and the reflectivity of the reflector.

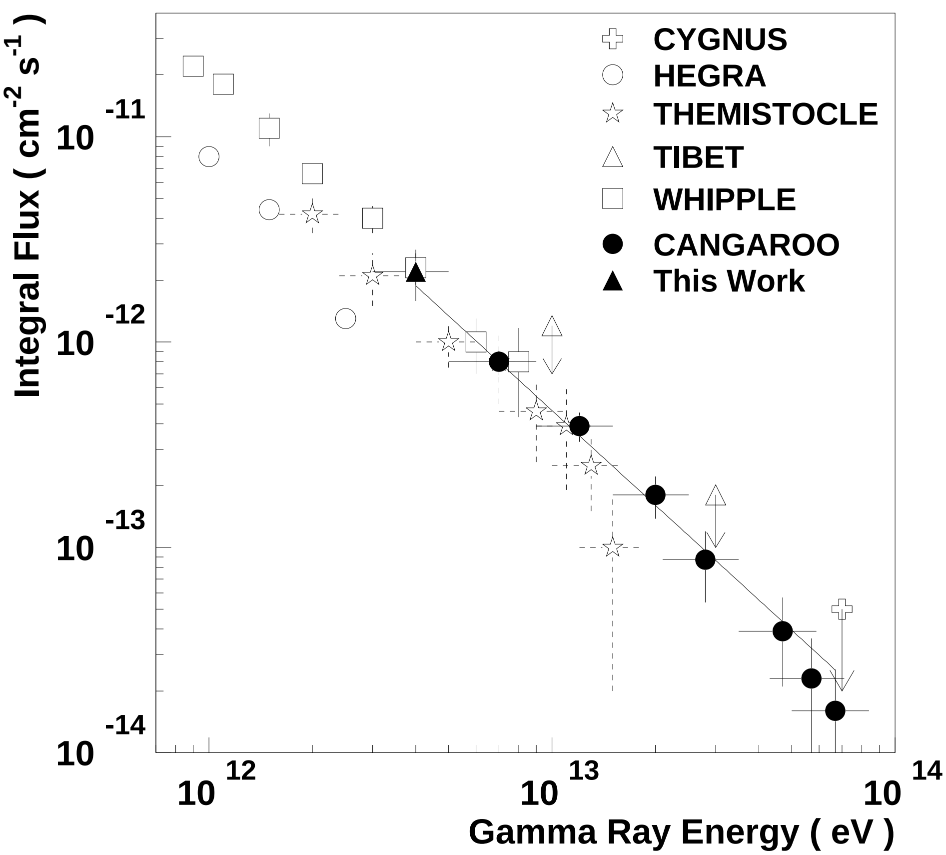

Figure 2: Integral Energy Spetrum of Crab pulsar/nebula

In addition, the integral spectrum of the background, cosmic rays, was calculated from the data, which were cut only "distance", to be $(9.4 \pm 0.3) \times 10^{-8}(E/10\,\mathrm{TeV})^{-1.72\pm0.04}$ cm^{-2}s^{-1} in the energy range of 13TeV to 110TeV, where all of background events are considered to be proton showers. Not only the integral index of cosmic rays can be reconstructed with good accuracy, but also the absolute flux is fairly consistent to the recent results of balloon born experiments within factor $\sim$3. Here the same procedure of the simulation was used to calculate the efficiencies of the trigger and analysis for proton showers.

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